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Smart meters for power grid: Challenges, issues, advantages and status

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ABSTRACT

Smart meter is an advanced energy meter that measures consumption of electrical energy providing additional information compared to a conventional energy meter. Integration of smart meters into electricity grid involves implementation of a variety of techniques and software, depending on the features that the situation demands. Design of a smart meter depends on the requirements of the utility company as well as the customer. This paper discusses various features and technologies that can be integrated with a smart meter. In fact, deployment of smart meters needs proper selection and implementation of a communication network satisfying the security standards of smart grid communication. This paper outlines various issues and challenges involved in design, deployment, utilization, and maintenance of the smart meter infrastructure. In addition, several applications and advantages of smart meter, in the view of future electricity market are discussed in detail. This paper explains the importance of introducing smart meters in developing countries. In addition, the status of smart metering in various countries is also illustrated.

Contents

1. Introduction

Smart meter is an advanced energy meter that measures the energy consumption of a consumer and provides added information to the utility company compared to a regular energy meter. Smart meters can read real-time energy consumption information including the values of voltage, phase angle and the frequency and securely communicates that data. The ability of smart meters for bidirectional communication of data enables the ability to collect information regarding the electricity fed back to the power grid from customer premises. A smart meter system includes a smart meter, communication infrastructure, and control devices. Smart meters can communicate and execute control commands remotely as well as locally. Smart meters can be used to monitor and also to control all home appliances and devices at the customer's premises. They can also collect diagnostic information about the distribution grid, home appliances, and can communicate with other meters in their reach. They can measure electricity consumption from the grid, support decentralized generation sources and energy storage devices, and bill the customer accordingly. Data collected by smart meters is a combination of parameters such as a unique meter identifier, timestamp of the data, and electricity consumption values. Smart meters can be programmed such that, only power consumed from the utility grid is billed while the power consumed from the distributed generation sources or storage devices owned by the customers is not billed. Smart meters can limit the maximum electricity consumption, and can terminate or re-connect electricity supply to any customer remotely [1,2]. Fig. 1 shows an architectural model of a conventional energy meter and a smart meter.

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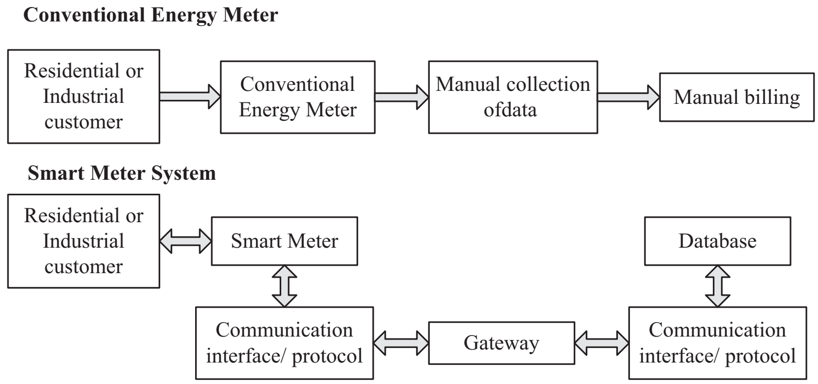


Fig. 1. Metering architectures of conventional energy meter and smart meter.

A smart meter system employs several control devices, various sensors to identify parameters and devices to transfer the data and command signals. In future electricity distribution grids, smart meters would play an important role in monitoring the performance and the energy usage characteristics of the load on the grid. Collection of energy consumption data from all customers on a regular basis allows the utility companies to manage electricity demand more efficiently and also to advise the customers about the cost efficient ways to use their appliances. In light of this, smart meters can be used to control light, heat, air conditioning and other appliances [3]. Smart meters can be programmed to maintain a schedule for operation of the home appliances and control operation of other devices accordingly. In addition, integration of smart meters helps utility companies in detecting unauthorized consumption and electricity theft in view of improving the distribution efficiency and power quality [4].

Design of future electricity markets is aimed at providing their consumers with highly reliable, flexible, readily accessible and cost-effective energy services by exploiting advantages of both large centralized generators as well as small distributed power generation devices [5]. In addition, distributed generation would be an essential integral part of future household energy systems. Utility companies try to identify more profitable customers to provide optional value added services, as smart meters can identify such customers based on the distributed generation sources and overall power consumption. With all these services and other demand side management techniques require utility companies to collect large quantity of real-time data.

Rest of the paper is organized in the following way: Section 2 details various communication network technologies to date; Section 3 discusses various issues and challenges in developing, deploying and maintaining the smart meters; Section 4 outlines the applications and advantages of introducing the smart meters replacing the existing metering and billing system; Section 5 illustrates the need for implementation of smart meters in developing countries; and Section 6 summarizes the status of implementation of smart meters.

2. Communication technologies

Of all design considerations, selection of the communication network and design of the communication devices are very important and must satisfy multiple complex requirements. As discussed earlier, utilization of the smart meter system involves a huge amount of data transfer between the utility company, smart meter, and home appliances in the network. This data is sensitive, confidential and access to this data should be restricted to a few personnel. With these restrictions on data, security guidelines are formulated for transmission, collection, storage, and maintenance of the energy consumption data. The communication standards and guidelines were formulated to ensure that data transfer within the network is secure. It is equally important that this data must represent the complete information regarding the energy consumption by the customer and status of the grids without any potential manipulations or miscalculations. So, this data must be authenticated and should reflect information about the target correct devices [6]. Fig. 2 shows the generic architecture of communication network that is capable of performing all the features discussed above. This figure illustrates the directionality of communication between the devices at the customer premises, utility, neighbor's smart meters, and other power system components.

In this figure, devices in the transmission sector ensure proper transmission of generated energy, control systems in distribution sector ensure monitoring and controlling faults, communication devices like protocol gateways, data collectors and repeaters and network operations coordinates data and control signals between all the devices in the communication network. A smart meter or an appliance that belongs to a customer can be identified by a unique identity assigned to it. In general, identities given to all components are secured by cryptographic techniques [7]. The communication network selected has to support operation of the smart meter system even on power outage detection and support distribution automation. In addition, the selected network and its components must be cost effective and must support "traffic prioritization" i.e., prioritize the delivery of data based on its time and direction sequence [8].

Communication technologies to be chosen have to be cost efficient, should provide good transmittable range, better security features, bandwidth, power quality and with least possible number of repetitions. Bluetooth technology can be a possible option for communication of control signals and to transmit energy consumption data. In the view of implementing this technique, Koay et al. proposed a Bluetooth based energy meter that can collect and transmit the energy consumption data wirelessly to a central base station [10]. Power Line Carrier (PLC) and Broadband Power Line (BPL) communications are the other possible options of data transfer supporting the higher level communication suites such as TCP/IP. One of the popular communication technologies is PLC, which uses the existing electricity grid, cellular/pager network, mesh network, combination of licensed and unlicensed radio, wireless modem, existing internet connection, power line communication [11], RS-232/485, Wi-Fi, WiMAX, and Ethernet with protocol to upload data using IEC DNP [12]. PLC technology is highly efficient for automation of data in smart meter applications [13]. In spite of substantial overhead caused by the large IPv6 header, this protocol can be applied even at low PHY layer data rates. This technology, with the combination of the MAC algorithm can achieve satisfactory delay times and throughput. Though this combina-

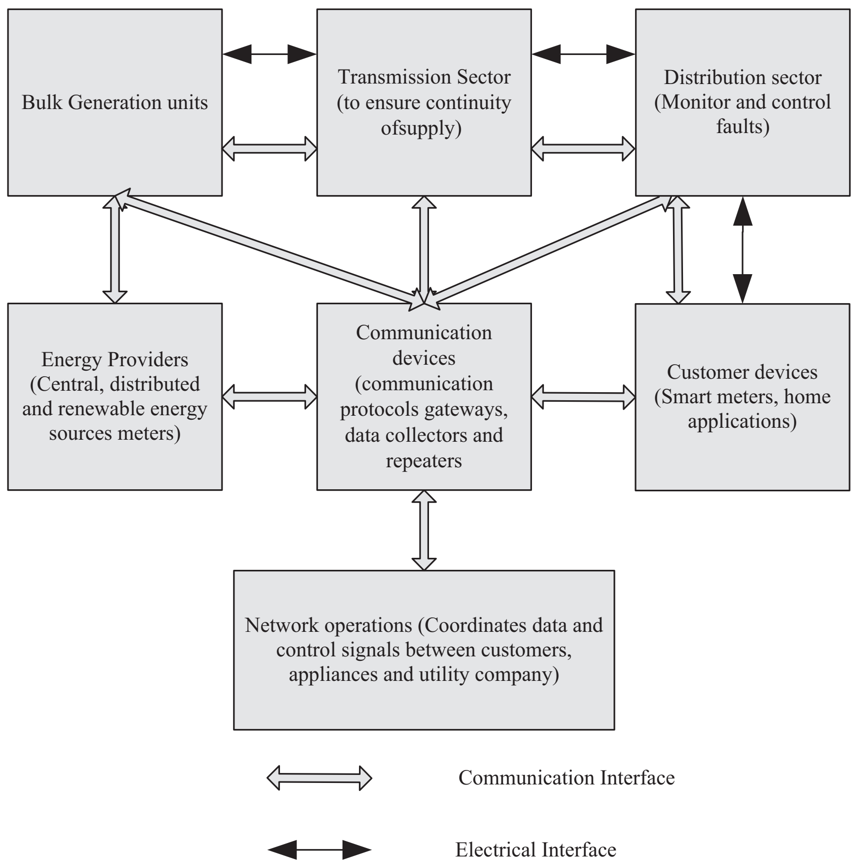


Fig. 2. Communication network in smart meter system [9].

tion might slightly reduce the usable data transfer rate, it will not affect the overhead at MAC layer [14]. IP based network protocol would be another promising option for communication because of its advantages over other technologies while satisfying the security standards of the smart grid communications. In addition, TCP/IP technology can also be used as a common platform for multiple communication devices [15].

In addition to above options, Session Initiation Protocol (SIP) is a text-based signaling protocol that is used for controlling multimedia sessions such as video and Voice over Internet Protocol (VoIP). SIP can be used on Transmission Control Protocol (TCP), User Datagram Protocol (UDP), or Stream Control Transmission Protocol (SCTP). SIP incorporates several elements of HTTP and Simple Mail Transfer Protocol (SMTP). SIP is an open and standard-based technology, which provides a robust communication medium for the smart grid applications [16]. Mander et al. proposed a communication architecture that uses DNP3 to produce the protocol discontinuity between the DNP3 devices for regulated power system operations and TCP/IP devices for the smart load and demand management. This discontinuity in protocols limits the number of vulnerable attacks from other TCP/IP devices. Some security enhancements such as data object security and a security layer to DNP3, as this protocol by itself is not adequately safe for collaborative operations. Data object security provides several rules for accessing the data in order to avoid unauthorized access that manipulates the data and device operations [17].

Rusitschka et al. proposed an energy meter that communicates using a Peer-to-Peer (P2P) based network. A smart meter that employs P2P network can enhance the range of operations of the appliances. In addition to such advantages, several value added services can also be implemented with less capability requirement. As the P2P based communication uses Internet, this can lead to cost effective design of smart grid communication network [18]. In addition, the P2P network utilizes the resources of participating homes optimally. Zigbee [19] network is another important and potential communication network for transfer of data and control signals. As many industrial and household entities maintain a computer with 802.11.x, Zigbee protocol can be used with Home Area Networks (HANs) for data transfer over 802.11.x [20]. Using this technology, instead of increasing the operating clock frequency in the crypto core in order to reduce the response time and verification delay, Kim et al. proposed the mode toggling approach on the design process for AES-CCM module. They have also adopted the optimal security material management module. These design methodologies and the obtained response time allow the cryptographic core to maintain the minimum clock frequency, while staying within the constraints, ensuring the reduction in total dynamic power consumption [21].

GPRS technology can be a potential communication medium for transferring both the data and control signals wirelessly over long distances. In contrary to other communication network technologies, only a few communication characteristics that represent GPRS communication network have been assessed. In view of this, lack of tools for detection of a network failure would be major setback for implementing GPRS network in many geographical locations. Before deploying a GPRS based communication system in a specific location, availability and quality of the signal have to be determined [22]. Parallel processing and implementation of field-programmable gate array (FPGA) hardware can reduce the total computation time for interpreting the data and to obtain the status of the distribution network. Adoption of reconfigurable logic for processing of data minimizes the amount of data to be generated by a smart meter [23]. Of all proposed and available possibilities of communication technologies, GPRS and PLC technologies are

currently implemented because of the ease in maintenance and economic factors.

3. Issues and challenges

In general view, efficient management of the grid can be an alternative solution instead of revamping the existing grid. But, in view of technical advantages and enhancements to operation capability, integration of the smart grid stands as a valuable solution in managing the existing grid. However, the design, deployment and maintenance of the smart meter system involve many issues and challenges. Implementation of smart meter system in the distribution system involves several billion dollars of investment for deployment and maintenance of the network. Indeed justifying the investment is difficult. Thus, this investment has to be realized as a function proportional to the projected increase in the energy demand and portion of the distributed generation [24]. Initially, the process of replacing the existing energy meters with a smart meter system will be a challenge for utility companies. Lack of proper infrastructure for synchronizing this new technology with the existing ones might interrupt the introduction of smart meters. Though several devices are integrated with the smart meter system, they can be used to their fullest extent only when all the appliances and devices in the distribution and metering network are included in the communication network. Integration of the devices becomes even more complicated with an increasing number of customers. Deployment of communication network in some localities might be difficult due to terrestrial difficulties [15]. In the USA, utility companies receive incentives for selling more electricity, which might not drive them to encourage their customers to conserve energy [1].

Collection and transmission of energy consumption data is a continuous process that is done automatically, but it is a tedious and expense job. In this context, a common notion might arise in several customers is that, smart meters they might essentially create some privacy and security risks as the data and signals are being transmitted. Additionally, this data might also reveal the information about presence of people at their residence, when they were present, and what appliances are in use. In view of this, some customers might be unwilling to communicate their energy consumption data with their neighbor's meter. Fundamentally, it would be an issue about the choice of parameters to be transmitted and administrator authentication to access that information [20,25].

In addition to communicating the data and control signals with the base station, smart meters must execute these control commands from the utility companies. Operation of a smart meter system involves a huge quantity of data transfer between a smart meter and the server located at the base station. Maintenance, management and storage of data could be a tedious job. There are many technical issues that might be considered during selection of communication network. For instance, DNP3 does not provide sufficient security for collaborative operations; therefore, some security enhancements to DNP3 are proposed by Mander et al. using data object security and a security layer [17]. In addition, most of the smart meter communication networks use low bandwidth, which generates high traffic and limits the quantity of data to be transmitted. Integration of devices for modulation, demodulation and additional memory for storing the data logs could increase the overall deployment costs. Energy consumption data transmitted through public communication networks like cellular networks might involve security risks [6]. Other possible security vulnerabilities might be weak authentication, quality of implemented software, error handling, weak protocols, and improper session management [26]. In spite of these issues, though deployment and maintenance of some communication networks are cheap, utility companies might encounter some challenges in the form of limitations in network coverage, data capacity, and propagation issues. In addition, data concentrators may lead to accommodation and safety issues. In case of wired communication, physical damage to the cable might also cause discontinuity in data transfer.

Figs. 3–5 illustrate various issues and challenges in design, deployment, utilization and maintenance of the smart meter system. Apart from utility companies, there are certain sections of people who might be interested in collecting and analyzing the energy consumption data of a customer. They include revengeful ex-spouses, civil litigants, illegal consumers of energy, extortionists, terrorists, political leaders with vested interests, thieves, etc. for knowledge about people's presence at their homes [27]. Quantification of the potential benefits from smart metering is very difficult due to the lack of historical data. Future of smart metering depends on the policies of utility companies and respective governments. Though customer gateways are intelligent and are easily compatible with other devices, they are prone to physical as well as cyber security risks [28,29]. In addition, energy meters are located in open and insecure environments and need proper shelter to be physically secure.

Fig. 3 illustrates several major design issues and constrains including the extent of technology to be included; this technology might include the kind of billing, control systems related software and other metering technology, the physical safety aspects such as

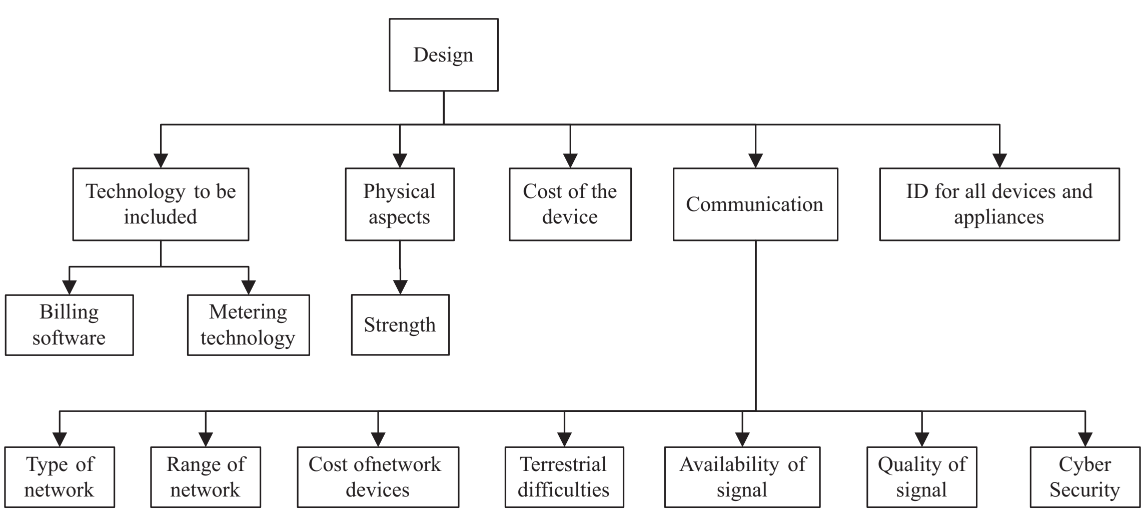


Fig. 3. Design issues for a smart meter system.

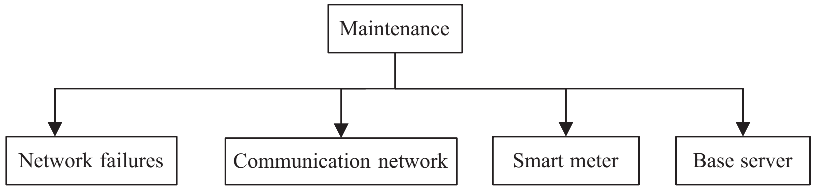


Fig. 4. Maintenance issues for a smart meter system.

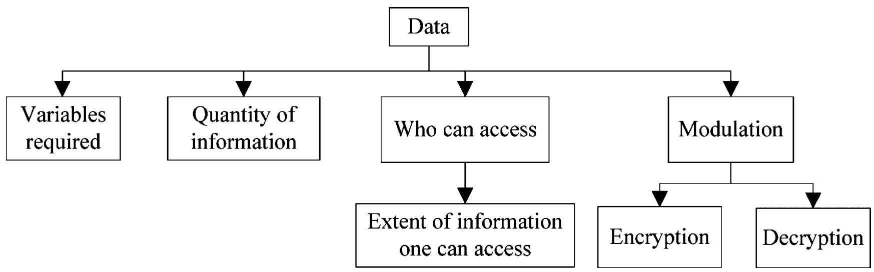


Fig. 5. Challenges with data transfer for a smart meter system.

positioning of the smart meter and physical strength of the structure that houses the smart meter components, cost of the smart meter devices, specific ID to identify all smart meters and other components in the smart meter network, and the type of communication infrastructure required, including overall cost for the data collectors, data repeaters, transmission, antenna system, type of network to be chosen based on terrestrial difficulties, availability of signal, cyber security, type of the signal and range of the signal. After deploying the required infrastructure, next major encounter would be the maintaining all the components of the network in case of any failure. Maintenance of network includes issues with the base server that stores the energy consumption data, software and hardware issues with the smart meter, electric network as well as distribution network failures. Besides these issues, dealing with the data could be another major issue. They include quantity of data to be transmitted, what are the variables to be transmitted, the extent and quantity of information that the customer and the utility companies, can access parameters, parameters required to represent the energy consumption, modulation of the data before transmission, demodulation of the data at the reception.

4. Applications and advantages

Smart Grid System determines the need of aspects such as daily workflow, workforce management, asset management, call center philosophy, and billing systematic. Smart meters can enhance the operation of SCADA system. As smart meter system provides several benefits such as efficient power system control and monitoring, operational decisions those are taken timely to minimize outages and losses [30]. Particularly in micro-grids, smart meters can perform energy cost allocation, fault analysis, demand control and power quality analysis. Smart meters can schedule preventive maintenance, and support the operation of check meters for accurate billing. In addition, smart meters can detect the presence of unwanted harmonic component in current supplied from the de-centrally generated sources, which helps in identification and rectification of the source of the problem [31]. Micro generators integrated into the distribution network must be registered, so that they are under the access and control of the smart meter system. Pattern recognition techniques can also be employed as part of the smart metering system in order to gain access to the performance information of the devices and financial incentives to the customer [32]. Manual energy meter reading is a tedious, continuous and an expensive job. In conventional metering system, meter reader has to go and take the reading manually to generate and issue the bill. This whole process can be simplified with the help of a smart meter and proper communication mechanism. Increased energy security as well as energy saving drives the installation and adoption of smart meters [3]. Smart meters encourage consumers to conserve energy by helping them maintain the quantity and cost of their energy consumption. There are several models of smart meters proposed by several researchers. Of which a few models are discussed in this section.

Power strip smart meters can be employed to monitor and control the appliances of customers. These meters provide data, identity and location of home appliances under operation [33]. Generally, unbalanced loads cause fluctuations in the voltage profile of a distribution feeder located far-away from the substation. Smart meters can analyze and control these fluctuations in low voltage grids [34]. Information about the load at the customer end and control of the maximum load demand helps utility companies in maintaining a flat voltage profile on the power supplied. Smart meters control the maximum load demand of a customer during peak load, and if any customer exceeds their limit, the supply of electricity will be disconnected to that customer [35].

Present electricity grids are designed for large scale generation, centralized control, transmission, and distribution of electricity. As such, these devices and system might not be efficient for housing intermittent power generation sources such as wind turbines and PV panels without compromising on the overall power system stability. In addition, present grid systems are designed for unidirectional power flow [36]. Integrating additional devices to the smart meter system enhances the capabilities of smart metering technology. Geographic Information System (GIS) can be integrated to the smart meter system in order to obtain specific information regarding the geographical location of a potential fault. Quick identification and rectification of faults and other issues that demand the attention of utility company reduce the overall power outage duration [30]. In addition, smart meters reduce the average power outage duration to 4–6 min due to their fast response and rectification to power outages and faults [37].

Claudio and Emilia proposed a smart total harmonic distortion (THD) meter that monitors the quality of the power supplied from the grid and evaluates the THD [38]. Particularly, when the distribution grid is integrated with wind turbines, occurrence of a fault similar to sudden disconnection of a generation unit or large load can alter the supply frequency. Smart meter system can quantify

and maintain these parameters within desirable range even under high wind circumstances [39].

In a smart meter system, a central control station at the utility company directs the smart meter at a customer premises to control the home appliances based on the preselected schedule for operation of devices that the customer opts for [40]. Implementation of smart meters enables the utility companies to change or introduce new tariff schemes. Apart from the discussed advantages, other major arguments for introducing smart meters are the possibility of introducing new and dynamic tariff schemes that allow benefits for the end customer. This would enable the possibility to provide demand response by shifting loads which helps in flattening the energy usage profile. In addition to time of use tariff and real-time pricing schemes [1], introduction of pre-paid smart card system [41] will allow utility companies to impose a reasonable tariff for the benefit of consumers. A smart card can be bought based on the consumer's load requirement and it can be recharged after consumption of the prepaid amount of energy. The prepaid smart card system reduces the possibility of billing irregularities [42]. Smart meters can be designed such that they can control illegal consumers from bypassing or tampering with the meter. They can manage the denial of service, hijacking, hacking, and control introduction of malware into the metering system.

Billing for the energy consumed by the customer is done with human intervention, which can be avoided using mobile agents to access the energy meters remotely. Each agent can be assigned a particular task for a particular location. Multiple mobile agents can be employed to overcome difficulties in accessing large amounts of data. Suriyakala and Sankaranarayanan proposed intelligent congestion controlling software that facilitates the operation of multiple mobile agents [43]. Das proposed a new communication system for existing energy meters, in which, the billing software is integrated with the communication mechanism so that the utility company can access any energy meter in the network and generate the bill remotely [7]. HAN technology can integrate load control devices with the target load and equipment to display the data related to overall energy consumption and other power quality parameters. HAN technology supports plug-in hybrid electric vehicles (PHEVs) and distributed energy generation facilities in the communication network. Penetration rate of PHEVs is expected to grow very high in future, which implies great ease for numerous smart meter applications. Environmental savings because of utilizing the energy from renewable energy sources can be calibrated and displayed on smart meters. Displaying such information might encourage some customers to use PVs and wind energy technologies instead of consuming energy generated from fossil fuels based generation units [9,44]. Energy web ecosystem proposed by Tuan allows consumers to monitor the parameters of distributed generation units and their load on grid. This might acquire attention of consumers and involve them in operation of the power systems while encouraging large scale integration of renewable energy sources [45].

5. Smart meters for developing countries

In many developing countries, conventional energy meters are used for billing the energy consumed by customers. For ease of operation of the home appliances, monitoring the grid, improving the power quality, improved load sharing, detecting non-technical losses, and other implied advantages, smart meters are to be introduced in developing countries. Power utility companies worldwide lose about 20 billion dollars each year because of non-technical losses [4]. In addition, growing non-technical losses because of theft and billing irregularities force the utility companies to implement a transparent and genuine metering system. However, deployment of smart grid and smart meter system involves huge budgets. It would be very difficult for utility companies to invest billions of dollars on an infrastructural upgrade that has no direct return on the investment. Therefore, smart meters with minimum required, but essential features may be designed for implementation in countries with weaker economy. So, smart meters might not be implemented for luxury in operation, but they must be introduced in order to fight the basic problems that power utility companies and its customers face. Smart meters with great networking capability and advanced software tools are difficult to tamper and hack, which improves the distribution efficiency. Integration of smart meters enhances facilitation of decentralized generation and power storage devices. In the near future, total energy demand is expected to become double the current demand. In view of this situation, many developing countries do not have resources for the additional capacity addition. To fill this gap, apart from increasing the installed generation capacity, controlling the electricity theft and regularizing the existing electricity customers can manage the load within demands.

6. Status of smart metering

In view of the advantages and applications, smart meter systems are being under large scale deployment worldwide. For instance, Austin Energy, one of the largest electric utility companies in the US with about 400,000 customers, has begun deploying smart meters to about 260,000 residential customers in 2008 [46]. Centerpoint Energy, a Houston based utility company will have deployed smart meters to about 2 million customers by the year 2012 in the Houston-Metro and Galveston service locations. In US, targeted implementation of smart meters requires an investment of about $50 billion. In North America, penetration rate of smart meters was about 6% in the year 2008 and is expected to reach 89% by 2012 [1].

By the year 2014, worldwide deployment of smart meters is expected to reach about 212 million units. In Italy, Enel, the third-largest energy provider in Europe has started deploying smart meters to about 27 million customers, which is the world's largest smart meter deployment project [47]. In Canada, the government of Ontario has planned to deploy smart meters to about 800,000 consumers including both residential and small businesses by the year 2007 [48]. In Korea, Korea Electric Power Corporation (KEPCO) started implementation of AMR based energy metering system for its industrial customers in 2000. Currently, these meters automatically transmit the energy consumption information from about 130,000 high voltage consumers. Using these smart metering systems, KEPCO provides value added services for about 55,000 of their low-voltage customers [49]. In Australia, the Essential Services Commission has mandated installation of interval meters for 2.6 million electricity consumers in Victoria. In 2007, the Dutch government has proposed a policy that mandated the adoption of smart meters to 7 million residential consumers by the year 2013. Later, the government went back on its policy and left the decision about installation to the consumer's interest because of the privacy and security concerns [50].

7. Conclusion

This paper reviews several important aspects of smart metering. It explains advantages of smart meter system from utility company as well as in customer point of view. Various potential communication networks for smart meter communication are presented in detail. In addition, several challenges, requirements and issues in design, development, deployment, and maintenance of the smart meter systems are discussed. Finally, need for smart meters in developing countries and status of worldwide installation of smart meters are illustrated.

References

[1] Vojdani A. Smart integration. IEEE Power & Energy Magazine November 2008;6:71–9.
[2] Hart DG. Using AMI to realize the smart grid. In: Proc. IEEE Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy. 2008. p. 1–2.
[3] Gerwen R, Jaarsma S, Wilhite R. Smart metering. Available from: http://www.leonardo-energy.org/webfm_send/435.
[4] Depuru SS, Wang L, Devabhaktuni V. A conceptual design using harmonics to reduce pilfering of electricity. In: IEEE PES General Meeting. 2010. p. 1–7.
[5] Chebbo M. EU smart grids framework: electricity networks of the future 2020 and beyond. In: Proc. IEEE Power Engineering Society General Meeting. 2007. p. 1–8.
[6] Cleveland FM. Cyber security issues for advanced metering infrastructure. In: Proc. IEEE Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy. 2008. p. 1–5.
[7] Das VV. Wireless communication system for energy meter reading. In: Proc. International Conference on Advances in Recent Technologies in Communication and Computing. 2009. p. 896–8.
[8] Gunther EW. NIST conceptual model: overview and evolution. Available from: http://www.ietf.org/proceedings/10mar/slides/intar ea-7.pdf.
[9] Smart grids. Carbonmetrics. Available online http://www.carbonmetrics.eu/Smart-Grids.php.
[10] Koay BS, Cheah SS, Sng YH, Chong PHJ, Shum P, Tong YC, et al. Design and implementation of bluetooth energy meter. In: Proc. Fourth International Conference on Information, Communications & Signal Processing. 2003. p. 1474–7.
[11] Son YS, Pulkkinen T, Moon KY, Kim C. Home energy management system based on power line communication. IEEE Transactions on Consumer Electronics August 2010;56:1380–6.
[12] Lee PK, Lai LL. A practical approach of smart metering in remote monitoring of renewable energy applications. In: Proc. IEEE Power & Energy Society General Meeting. 2009. p. 1–4.
[13] Huczala M, Lukl T, Misurec J. Capturing energy meter data over secured power line. In: Proc. International Conference on Communication Technology. 2006. p. 1–4.
[14] Bauer M, Plappert W, Chong W, Dostert K. Packet-oriented communication protocols for smart grid services over low-speed PLC. In: Proc. IEEE International Symposium on Power Line Communications and Its Applications. 2009. p. 89–94.
[15] Press release: Cisco outlines strategy for highly secure. Smart Grid Infrastructure. Available from: http://newsroom.cisco.com/dlls/2009/prod_051809.html.
[16] DiAdamo J. SIP: the clear choice for smart grid communications. Available from: http://www.smartgridnews.com/artman/publish/Technologies_Standards_News/SIP_The_Clear_Choice_for_Smart_Grid_Communications-604.html.
[17] Mander T, Cheung H, Hamlyn A, Lin W, Cungang Y, Cheung R. New network cyber-security architecture for smart distribution system operations. In: Proc. IEEE Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy. 2008. p. 1–8.
[18] Rusitschka S, Gerdes C, Eger K. A low-cost alternative to smart metering infrastructure based on peer-to-peer technologies. In: Proc. International Conference on the European Energy Market. 2009. p. 1–6.
[19] Han DM, Lim JH. Smart home energy management system using IEEE 802.15.4 and zigbee communication. IEEE Transactions on Consumer Electronics August 2010;56:1403–10.
[20] Bennett C, Highfill D. Networking AMI smart meters. In: Proc. IEEE Energy 2030 Conference. 2008. p. 1–8.
[21] Kim J, Lee J, Song O. Power-efficient architecture of zigbee security processing. In: Proc. International Symposium on Parallel and Distributed Processing with Applications. 2008. p. 773–8.
[22] Cuvelier P, Sommereyns P. Proof of concept smart metering. In: Proc. International Conference and Exhibition on Electricity Distribution. 2009. p. 1–4.
[23] Hafner A, Lima CRE, Lopes HS. An electric energy quality meter using hardware reconfigurable computing. In: Proc. IEEE Conference on Industrial Electronics and Applications. 2006. p. 1–6.
[24] Hallberg P. Smart grids and networks of the future – eurelectric views. Available from: www.eurelectric.org/Download/Download.aspx?DocumentID=26620.
[25] Silva D. New ‘smart’ electrical meters raise privacy issues. Available from: http://www.physorg.com/news176703307.html.
[26] Robinson RE, Stuber MG. Itron white paper: advanced metering infrastructure risk analysis for advanced metering. Available from: www.itron.com/asset.asp?path=support/whitepaper/pdf/itr_016898.pdf.
[27] Foley MF. The dangers of meter data (part 1). Available from: http://www.smartgridnews.com/artman/publish/industry/The_Dangers_of_Meter_Data_Part_1.html.
[28] Cohen F. The smarter grid. IEEE Security & Privacy January 2010;8:60–3.
[29] Ericsson GN. Cyber security and power system communication-essential parts of a smart grid infrastructure. IEEE Transactions on Power Delivery July 2010;25:1501–7.
[30] Mahmood A, Aamir M, Anis MI. Design and implementation of AMR smart grid system. In: Proc. IEEE Canada Electric Power Conference. 2008. p. 6–7.
[31] Lee PK, Lai LL. Smart metering in micro-grid applications. In: Proc. IEEE Power & Energy Society General Meeting. 2009. p. 1–5.
[32] Boait P. Smart metering of renewable micro generators by output pattern recognition. In: Proc. International Conference and Exhibition on Electricity Distribution. 2009. p. 1–4.
[33] Sang CH, Yamazaki T, Minsoo H. Determining location of appliances from multi-hop tree structures of power strip type smart meters. IEEE Transactions on Consumer Electronics November 2009;55:2314–22.
[34] Abart A, Lugmair A, Schenk A. Smart metering features for managing low voltage distribution grids. In: Proc. International Conference and Exhibition on Electricity Distribution. 2009. p. 1–4.
[35] Maitra S. Embedded energy meter – a new concept to measure the energy consumed by a consumer and to pay the bill. In: Proc. Joint International Conference on Power System Technology and IEEE Power India Conference. 2008. p. 1–8.
[36] He MM, Reutzel EM, Xiaofan J, Katz RH, Sanders SR, Culler DE, et al. An architecture for local energy generation, distribution, and sharing. In: Proc IEEE Energy 2030 Conference. 2008. p. 1–6.
[37] Tram H. Technical and operation considerations in using smart metering for outage management. In: Proc. IEEE/PES Transmission and Distribution Conference and Exposition. 2008. p. 1–3.
[38] Claudio C, Emilia R. Smart THD meter performing an original uncertainty evaluation procedure. IEEE Transactions on Instrumentation and Measurement August 2007;56:1257–64.
[39] Samarakoon K, Ekanayake J. Demand side primary frequency response support through smart meter control. In: Proc. 44th International Universities Power Engineering Conference (UPEC). 2009. p. 1–5.
[40] Cheng J, Kunz T. A survey on smart home networking. Technical Report SCE-09-10, Carleton University. Available from: http://kunz-pc.sce.carleton.ca/Thesis/SmartHomeNetworking.pdf.
[41] Cowburn J. Paying for energy the smart way. IEE Review July 2001;47:17–20.
[42] Deconinck G, Decroix B. Smart metering tariff schemes combined with distributed energy resources. In: Proc. Fourth International Conference on Critical Infrastructures. 2009. p. 1–8.
[43] Suriyakala CD, Sankaranarayanan PE. Smart multiagent architecture for congestion control to access remote energy meters. In: Proc. International Conference on Computational Intelligence and Multimedia Applications. 2007. p. 24–8.
[44] Valigi E, Marino E. Networks optimization with advanced meter infrastructure and smart meters. In: Proc. International Conference and Exhibition on Electricity Distribution. 2009. p. p.1–4.
[45] Tuan D. The energy web: concept and challenges to overcome to make large scale renewable and distributed energy resources a true reality. In: Proc. 7th IEEE International Conference on Industrial Informatics. 2009. p. 384–9.
[46] Landis+Gyr technology enables full service smart grid coverage. Available from: http://www.reuters.com/article/idUS191587+31-Mar-2009+PRN20090331.
[47] Smart Meters. Available from: http://climatelab.org/Smart_Meters.
[48] In depth: smart meters: FAQs. Available from: http://www.cbc.ca/news/background/energy/smartmeters.html.
[49] Il-Kwon Y, Nam-Joon J, Young-Il K. Status of advanced metering infrastructure development in Korea. In: Proc. Transmission & Distribution Conference & Exposition: Asia and Pacific. 2009. p. 1–3.
[50] Smart energy meter will not be compulsory. Available from: http://www.nrc.nl/international/article2207260.ece/Smart_energy_meter_will_not_be_compulsory.